

seen in basaltic rocks, were also observed. A small quantity of the liquid did not crystallise at all, but became glassy at low temperature.

Normal Hexane (Kahlbaum's, from propyl iodide).—*n*-Hexane crystallises in needle-shaped prisms which exhibit extinction angles of very different degree. The double-refraction is moderately high. At liquid air temperature a very distinct longitudinal cleavage is developed. No polymorphic change takes place above -200° , but at low temperature sparse twinning lamellæ are formed, lying at an angle of about 80° to the prism axis; *n*-hexane is thus monoclinic or triclinic, probably monoclinic.

Normal Heptane (Kahlbaum's, from petroleum).—The commercial product does not crystallise well, and a homogeneous preparation could no more be obtained in this case than in the case of *n*-pentane. The principal crystallisation product of the middle fractions consisted of long monoclinic or triclinic needles.

Normal Octane (Kahlbaum's, from *n*-butyl iodide).—*n*-Octane crystallises well and in large prismatic columns of moderately high double-refraction. It is monoclinic or triclinic. No polymorphic transition has been observed above -200° .

Ammonium Ferrous Sulphate and its Alkali-metal Isomorphs.

By A. E. H. TUTTON, D.Sc., M.A., F.R.S.

(Received March 11,—Read March 13, 1913.)

Ammonium ferrous sulphate, $(\text{NH}_4)_2\text{Fe}(\text{SO}_4)_2 \cdot 6\text{H}_2\text{O}$, although one of the commonest double salts in everyday laboratory use, and noted for its excellent, comparatively stable, clearly transparent, pale greenish-blue crystals, has never yet been subjected to a thorough crystallographic and optical study. Since the year 1859, when a few of its principal angles were measured by Murmann and Rotter,* and an approximate idea of its optical properties for red, yellow, and green light of no specific wave-lengths briefly indicated, just adequately to confirm that the salt belongs to the monoclinic series of double sulphates crystallising with $6\text{H}_2\text{O}$, no accurate measurements have been made. The substance has, however, formed the subject of several special researches from a different point of view, such as those of von Hauer† on the parallel growths of this salt on crystals of other salts of the series, of

* Murmann and Rotter, 'Sitzungsber. d. Akad. d. Wiss. Wien,' 1859, vol. 34, p. 153.

† K. von Hauer, 1860, *ibid.*, vol. 39, p. 611.

Baumhauer* concerning the etch-figures produced on the various faces of the crystals by a small quantity of water, by St. Meyer† on the nature of the crystals deposited under the influence of a magnetic field, by Wulff‡ on the different rapidity of growth of the different crystal faces, and by von Fedorow§ concerning the correct setting of the crystals for descriptive purposes. But this salt was not included in the well-known series of optical investigations of Topsøe and Christiansen in 1874–5, nor the later one of Perrot, and has not been hitherto included by the author in his detailed investigation of the salts of this isomorphous series. This omission is now, however, removed by this communication.

Morphology.

In common with the whole of the salts of the large isomorphous series, $R_2M \left\{ \begin{matrix} S \\ SeO_4 \\ Cr \end{matrix} \right\} \cdot 2.6H_2O$, ammonium ferrous sulphate crystallises in the monoclinic system with full holohedral symmetry. That the class is the holohedral one (Class 5, holohedral-prismatic) was proved by Baumhauer as the result of his investigation of the etch-figures afforded by water (see figs. 8 and 9, on pp. 371 and 372).

Crystal System.—Monoclinic. Class No. 5, holohedral-prismatic.

Ratios of Axes.— $a : b : c = 0.7377 : 1 : 0.4960$. Values of Murmann and Rotter, $0.7466 : 1 : 0.4950$.

Axial Angle.— $\beta = 106^\circ 50'$. Value of Murmann and Rotter, $106^\circ 48'$.

Forms observed.— $b\{010\}$, $c\{001\}$, $p\{110\}$, $p'''\{130\}$, $q\{011\}$, $r'\{\bar{2}01\}$, $o\{111\}$, $o'\{\bar{1}11\}$.

Habit.—Chiefly tabular parallel to $r'\{\bar{2}01\}$; frequently elongated along the edge $[20\bar{1} : 010]$, or $[20\bar{1} : 110]$; occasionally with $c\{001\}$, $p\{110\}$, $r'\{\bar{2}01\}$, and $q\{011\}$ more or less equally developed. Murmann and Rotter also observed a tabular form parallel to $r'\{\bar{2}01\}$, prolongation along the edge $[201 : 1\bar{1}0]$, and predominating development of $c\{001\}$, $p\{110\}$, and $r'\{\bar{2}01\}$, with subordinated $q\{011\}$, $o'\{\bar{1}11\}$, and $b\{010\}$, the latter type being shown in fig. 1.

The salt is thus characterised by predominating development of the pair of parallel faces of the form $r'\{\bar{2}01\}$, which is usually only a subordinate one for the series in general. Three typical crystals measured by the author are represented in figs. 2, 3, and 4. The types 3 and 4 are clearly tabular

* H. Baumhauer, 'Pogg. Ann. d. Phys.,' 1873, vol. 150, p. 619.

† St. Meyer, 'Sitzungsber. d. Akad. d. Wiss. Wien,' 1899, vol. 108 (11A), p. 513.

‡ G. Wulff, 'Zeitschr. für Kryst.,' 1901, vol. 34, p. 486.

§ E. von Fedorow, 1909, *ibid.*, vol. 46, p. 258.

parallel $r'\{\bar{2}01\}$, and type 4 is only distinguished from type 3 by the larger development of the faces of the basal plane $c\{001\}$ and clinodome $q\{011\}$. The next best developed faces are those of the primary prism $p\{110\}$ and of the hemipyramid $o'\{\bar{1}11\}$, which are present to about the same extent, modifying the edges of $r'\{\bar{2}01\}$. The two faces of the clinopinakoid $b\{010\}$ are usually present, and in type 2 the crystal is elongated in the direction of

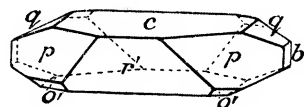


FIG. 1.

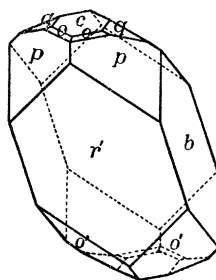


FIG. 2.

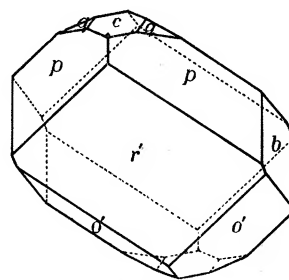


FIG. 3.

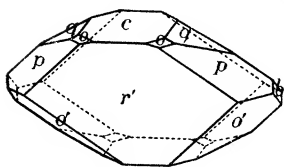


FIG. 4.

Typical Crystals of Ammonium Ferrous Sulphate.

the edge br' , so that the b -faces are long and narrow. Good little faces of the hemipyramid $o\{111\}$ were present on two of the measured crystals, and very narrow faces of $p'''\{130\}$ were discovered on one crystal, but their signal-images were neither sufficiently clear nor adequately free from diffraction to be of use other than for identification purposes.

Twelve excellent crystals were measured, of which ten were small and very perfectly formed, while two were larger, but yet gave excellent single images of the Websky signal. The crystals were selected from four different crops, which had been grown under ideal conditions of slow deposition and freedom from disturbance. These measured crystals in general yielded splendidly sharp and clear images of the signal, as will be obvious from the excellent agreement between the measured and calculated angles in the following table of angles. Other crops were considerably influenced by striation of the c - and p -faces, an occurrence which has been shown to be general throughout this series of double salts.

Table of Angles.—The following table presents the results of the measurements and calculations. The values of Murmann and Rotter, and also some earlier ones of Kopp,* are included in the last two columns.

* Cited in Rammelsberg, 'Handbuch d. kryst. phys. Chemie,' Leipzig, 1881, vol. 1, p 460.

Interfacial Angles of Ammonium Ferrous Sulphate.

Angle.	No. of measurements.	Limits.	Mean observed.	Calculated.	Diff.	Values of	
						M. & R.	Kopp.
$\begin{cases} ac = (100) : (001) \\ as = (100) : (101) \\ sc = (101) : (001) \\ cr' = (001) : (201) \\ cs' = (001) : (101) \\ s'r' = (101) : (201) \\ r'a = (201) : (100) \\ r'c = (201) : (001) \end{cases}$	$\begin{matrix} - \\ - \\ - \\ 13 \\ - \\ - \\ - \\ 14 \end{matrix}$	$\begin{matrix} \circ & ' & \circ & ' \\ - & - & - & - \\ 64 & 26- & 64 & 42 \\ - & - & - & - \\ - & - & - & - \\ - & - & - & - \\ - & - & - & - \\ 115 & 15-115 & 37 \end{matrix}$	$\begin{matrix} \circ & ' \\ - & - \\ - & - \\ 64 & 35 \\ - & - \\ - & - \\ - & - \\ 115 & 26 \end{matrix}$	$\begin{matrix} \circ & ' \\ 73 & 10 \\ 44 & 52 \\ 28 & 18 \\ 64 & 36 \\ 38 & 36 \\ 26 & 0 \\ 42 & 14 \\ 115 & 24 \end{matrix}$	$\begin{matrix} - \\ - \\ - \\ 1 \\ - \\ - \\ - \\ 2 \end{matrix}$	$\begin{matrix} \circ & ' \\ - & - \\ - & - \\ 64 & 5 \\ - & - \\ - & - \\ - & - \\ - & - \end{matrix}$	$\begin{matrix} \circ & ' \\ 73 & 12 \\ - & - \\ - & - \\ - & - \\ - & - \\ - & - \\ - & - \end{matrix}$
$\begin{cases} ap = (100) : (110) \\ pp' = (110) : (120) \\ p'b = (120) : (010) \\ pp'' = (110) : (130) \\ p''b = (130) : (010) \\ pb = (110) : (010) \\ pp = (110) : (1\bar{1}0) \end{cases}$	$\begin{matrix} - \\ - \\ - \\ - \\ - \\ 28 \\ 13 \end{matrix}$	$\begin{matrix} - \\ - \\ - \\ - \\ - \\ 54 & 40- & 54 & 55 \\ 70 & 23- & 70 & 31 \end{matrix}$	$\begin{matrix} - \\ - \\ - \\ - \\ - \\ 54 & 47 \\ 70 & 26 \end{matrix}$	$\begin{matrix} 35 & 13 \\ 19 & 28 \\ 35 & 19 \\ 29 & 30 \\ 25 & 17 \\ * \\ 70 & 26 \end{matrix}$	$\begin{matrix} - \\ - \\ - \\ - \\ - \\ - \\ 0 \end{matrix}$	$\begin{matrix} 54 & 29 \\ 71 & 7 \\ 25 & 16 \end{matrix}$	$\begin{matrix} - \\ - \\ - \\ - \\ - \\ - \\ 71 & 30 \end{matrix}$
$\begin{cases} cq = (001) : (011) \\ qb = (011) : (010) \end{cases}$	$\begin{matrix} 22 \\ 16 \end{matrix}$	$\begin{matrix} 25 & 12- & 25 & 34 \\ 64 & 27- & 64 & 41 \end{matrix}$	$\begin{matrix} 25 & 24 \\ 64 & 36 \end{matrix}$	$\begin{matrix} * \\ 64 & 36 \end{matrix}$	$\begin{matrix} - \\ 0 \end{matrix}$	$\begin{matrix} 25 & 16 \end{matrix}$	$\begin{matrix} 25 & 21 \end{matrix}$
$\begin{cases} ao = (100) : (111) \\ oq = (111) : (011) \\ aq = (100) : (011) \\ qo' = (011) : (111) \\ o'a = (111) : (100) \end{cases}$	$\begin{matrix} - \\ 1 \\ - \\ 3 \\ - \end{matrix}$	$\begin{matrix} - \\ - \\ - \\ 34 & 45- & 34 & 56 \\ - \end{matrix}$	$\begin{matrix} - \\ 26 & 55 \\ - \\ 34 & 51 \\ - \end{matrix}$	$\begin{matrix} 48 & 1 \\ 26 & 49 \\ 74 & 50 \\ 34 & 53 \\ 70 & 17 \end{matrix}$	$\begin{matrix} - \\ 6 \\ - \\ 2 \\ - \end{matrix}$	$\begin{matrix} - \\ - \\ - \\ - \\ - \end{matrix}$	$\begin{matrix} - \\ - \\ - \\ - \\ - \end{matrix}$
$\begin{cases} co = (001) : (111) \\ op = (111) : (110) \\ cp = (001) : (110) \\ po' = (110) : (11\bar{1}) \\ o'c = (111) : (00\bar{1}) \end{cases}$	$\begin{matrix} 3 \\ 3 \\ 21 \\ 24 \\ 21 \end{matrix}$	$\begin{matrix} 33 & 35- & 33 & 53 \\ 42 & 29- & 42 & 35 \\ 76 & 9- & 76 & 33 \\ 58 & 45- & 59 & 0 \\ 44 & 27- & 44 & 59 \end{matrix}$	$\begin{matrix} 33 & 45 \\ 42 & 31 \\ 76 & 19 \\ 58 & 54 \\ 44 & 47 \end{matrix}$	$\begin{matrix} 33 & 48 \\ 42 & 31 \\ * \\ 58 & 53 \\ 44 & 48 \end{matrix}$	$\begin{matrix} 3 \\ 0 \\ - \\ 1 \\ 1 \end{matrix}$	$\begin{matrix} 76 & 24 \\ 58 & 41 \\ 44 & 33 \end{matrix}$	$\begin{matrix} - \\ - \\ - \\ - \\ - \end{matrix}$
$\begin{cases} bn = (010) : (121) \\ no = (121) : (111) \\ bo = (010) : (111) \\ os = (111) : (101) \end{cases}$	$\begin{matrix} - \\ - \\ - \\ - \end{matrix}$	$\begin{matrix} - \\ - \\ - \\ - \end{matrix}$	$\begin{matrix} - \\ - \\ - \\ - \end{matrix}$	$\begin{matrix} 55 & 1 \\ 15 & 42 \\ 70 & 43 \\ 19 & 17 \end{matrix}$	$\begin{matrix} - \\ - \\ - \\ - \end{matrix}$	$\begin{matrix} - \\ - \\ - \\ - \end{matrix}$	$\begin{matrix} - \\ - \\ - \\ - \end{matrix}$
$\begin{cases} bo' = (010) : (111) \\ o's' = (111) : (101) \\ o'o' = (111) : (11\bar{1}) \end{cases}$	$\begin{matrix} 32 \\ - \\ 16 \end{matrix}$	$\begin{matrix} 65 & 8- & 65 & 20 \\ - \\ 49 & 21- & 49 & 40 \end{matrix}$	$\begin{matrix} 65 & 15 \\ - \\ 49 & 30 \end{matrix}$	$\begin{matrix} 65 & 16 \\ 24 & 44 \\ 49 & 28 \end{matrix}$	$\begin{matrix} 1 \\ - \\ 2 \end{matrix}$	$\begin{matrix} - \\ - \\ - \end{matrix}$	$\begin{matrix} - \\ - \\ - \end{matrix}$
$\begin{cases} sq = (101) : (011) \\ qp = (011) : (110) \\ ps = (110) : (101) \\ pq = (110) : (01\bar{1}) \end{cases}$	$\begin{matrix} - \\ 8 \\ - \\ 8 \end{matrix}$	$\begin{matrix} - \\ 87 & 54- & 88 & 5 \\ - \\ 91 & 55- & 92 & 6 \end{matrix}$	$\begin{matrix} - \\ 88 & 1 \\ - \\ 91 & 59 \end{matrix}$	$\begin{matrix} 37 & 19 \\ 88 & 4 \\ 54 & 37 \\ 91 & 56 \end{matrix}$	$\begin{matrix} - \\ 3 \\ - \\ 3 \end{matrix}$	$\begin{matrix} - \\ - \\ - \\ - \end{matrix}$	$\begin{matrix} - \\ - \\ - \\ - \end{matrix}$
$\begin{cases} s'q = (101) : (011) \\ qn = (011) : (121) \\ np = (121) : (110) \\ qp = (011) : (110) \\ ps' = (110) : (101) \\ pq = (110) : (01\bar{1}) \end{cases}$	$\begin{matrix} - \\ - \\ - \\ 10 \\ - \\ 10 \end{matrix}$	$\begin{matrix} - \\ - \\ - \\ 62 & 29- & 62 & 39 \\ - \\ 117 & 21- & 117 & 31 \end{matrix}$	$\begin{matrix} - \\ - \\ - \\ 62 & 34 \\ - \\ 117 & 26 \end{matrix}$	$\begin{matrix} 45 & 6 \\ 26 & 10 \\ 36 & 23 \\ 62 & 33 \\ 72 & 21 \\ 117 & 27 \end{matrix}$	$\begin{matrix} - \\ - \\ - \\ 1 \\ - \\ 1 \end{matrix}$	$\begin{matrix} - \\ - \\ - \\ - \\ - \\ - \end{matrix}$	$\begin{matrix} - \\ - \\ - \\ - \\ - \\ - \end{matrix}$
$\begin{cases} r'o' = (201) : (111) \\ o'p = (111) : (110) \\ p'r' = (110) : (201) \end{cases}$	$\begin{matrix} 34 \\ 33 \\ 33 \end{matrix}$	$\begin{matrix} 35 & 11- & 35 & 25 \\ 91 & 49- & 92 & 2 \\ 52 & 38- & 52 & 54 \end{matrix}$	$\begin{matrix} 35 & 18 \\ 91 & 55 \\ 52 & 47 \end{matrix}$	$\begin{matrix} 35 & 16 \\ 91 & 57 \\ 52 & 47 \end{matrix}$	$\begin{matrix} 2 \\ 2 \\ 0 \end{matrix}$	$\begin{matrix} - \\ - \\ - \end{matrix}$	$\begin{matrix} - \\ - \\ - \end{matrix}$
Total number of measurements...	366						

Cleavage.—The crystals cleave fairly readily parallel to $r'\{\bar{2}01\}$, as is general throughout this isomorphous series.

Crystallisation in a Magnetic Field.—As the result of a series of experiments on the deposition of various salts from their saturated solutions under the influence of a magnetic field, St. Meyer* found that in the case of ammonium ferrous sulphate tabular crystals separate, the shorter diagonal of which coincides with the lines of force; this diagonal is parallel to the symmetry plane, and it would appear from St. Meyer's description that the plates are parallel to $r'\{\bar{2}01\}$.

Rapidity of Growth of Different Faces and the Correct Setting.—The exceptional predominance of the orthopinakoid of the second order $r'\{\bar{2}01\}$ formed the subject of the investigation of Wulff† already alluded to. He found the relative rapidity of growth of the various forms to be in the following ascending order: $r'\{\bar{2}01\}$, $p\{110\}$, $c\{001\}$, $o\{111\}$, $o'\{\bar{1}11\}$, and $q\{011\}$. He gives an interesting figure, which is reproduced somewhat smaller in fig. 5, representing the result of immersing a crystal of ammonium zinc

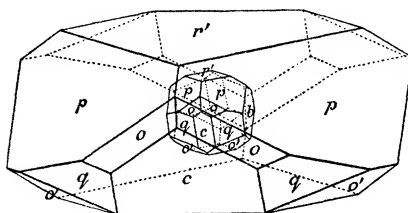


FIG. 5.—A Crystal of Ammonium Ferrous Sulphate growing on one of Ammonium Zinc Sulphate.

sulphate, with precisely equally developed faces, in a slightly supersaturated solution of ammonium ferrous sulphate. The crystal was suspended in the solution by means of a platinum wire hook. According to the experience of both von Hauer and Wulff ammonium ferrous sulphate is the most soluble double sulphate of the series, so that a crystal of ammonium zinc sulphate does not dissolve in a saturated solution of ammonium ferrous sulphate, but, on the contrary, the latter salt at once begins to crystallise as a layer or zonal overgrowth on the crystal of the ammonium zinc salt. Instead, however, of the equal continuation of growth on the equally grown different faces of the latter salt, the resulting crystal at the end of another similar period of time shows the relative development of faces represented in fig. 5, which is drawn from the correct relative amounts of development already described as having been determined by Wulff. First comes $r'\{\bar{2}01\}$ largely

* St. Meyer, 'Sitzungsber. d. Akad. d. Wiss. Wien,' 1899, vol. 108, (11A), p. 513.

† G. Wulff, 'Zeitschr. für Kryst.,' 1901, vol. 34, p. 486.

predominating, then next in successive order $p\{110\}$ and $c\{001\}$. For the slower the deposition of molecules on any given face, the more does that face predominate, on account of the more rapid growth of the crystal substance on its margins by the more rapid growth of the neighbouring faces.

It is to be remembered in this connection that the following facts have been clearly proved by the work of Bravais, Sohncke, and Curie, and again confirmed more recently by the researches both of Wulff and of von Fedorow.

The faces which are most frequently developed on crystals, and also those which predominate as regards extent of development, as well also as the cleavage planes and those parallel to which tabularity occurs, are precisely those which are most densely strewn with the points of the space-lattice.

With reference to the remarkable predominance of $r'\{\bar{2}01\}$ on ammonium ferrous sulphate, Wulff goes so far as to consider it fundamental, and proposes a new setting of the crystal in which the pair of parallel r' -faces are taken as those of the basal plane $\{001\}$. The next form in importance p becomes $\{1\bar{1}1\}$ on this setting. The crystal is represented in fig. 5 in accordance with it.

It must be remembered, however, that this predominant development of r' is an exceptional one, when the whole isomorphous series is considered. Among the 38 salts of the series which have now been exhaustively dealt with by the author only one, rubidium cadmium sulphate, has shown a similar predominance of r' , although in four other cases this form has been observed largely but not predominatingly developed, namely, in rubidium ferrous sulphate, caesium ferrous sulphate, potassium copper sulphate, and caesium copper sulphate. In general throughout the series the faces of the primary prism $p\{110\}$ and of the basal plane $c\{001\}$ vastly predominate, with the faces of $q\{011\}$ and $o'\{\bar{1}11\}$ following closely after in relative extent of development. Wulff himself mentions that $p\{110\}$ predominates on the crystals of ammonium zinc sulphate, even to as large an extent as does $r'\{\bar{2}01\}$ on ammonium ferrous sulphate. He ascribes the difference as due to the mode of growth of the two salts in the crystallisation vessel. Those of the ammonium zinc salt usually grow with either $p\{110\}$ or $c\{001\}$ in contact with the bottom of the vessel, and very rarely on $b\{010\}$, a form which is singularly seldom well developed, as regards extent, throughout the whole series. Moreover, the ammonium zinc salt never grows upon an $r'\{\bar{2}01\}$ face. On the other hand, ammonium ferrous sulphate crystals grow best of all on the r' -plane, as well as readily upon $c\{001\}$ and $p\{110\}$, but never upon $b\{010\}$. It would thus appear that Wulff is correct as regards this explanation of the difference of habit.

It is interesting to remark that this fact of ready growth on the r' -plane may be connected with St. Meyer's observation, that when ammonium ferrous sulphate is crystallised in a magnetic field the crystals take the form of plates parallel to $r'\{\bar{2}01\}$. For, as this salt is highly magnetic, there can be no surprise if the earth's magnetism should produce the same effect as an artificial magnetic field, and cause the deposition of tabular crystals parallel to $r'\{\bar{2}01\}$.

Moreover, as regards habit, it has been shown by the author that the alkali base present, in the cases of potassium, rubidium, and caesium, has a definite influence on the habit, which is most marked in the case of the basal plane $c\{001\}$; the faces of this form are, as a rule, relatively very large in the potassium salt, very narrow in the caesium salt, and of intermediate size in the rubidium salt. This influence is absent in the non-metallic ammonium salt, leaving other influences more free to act.

The "setting" of the crystals of the salts of this series has been gone carefully into by von Fedorow.* The setting employed by the author,† in this and all previous communications concerning this series, is that which was given by Murmann and Rotter, and, as it is the most natural one in precise keeping with the undoubtedly holohedral monoclinic symmetry of the crystals, was adopted by the author in the absence of any opposing reason.

It has been shown that this setting is preferable to that proposed by Wulff, when the development of faces throughout the whole series is generally considered, and von Fedorow confirms this view from the standpoint of the rule regarding reticular density. Both the settings of Wulff and of the author agree with monoclinic symmetry, but Wulff rotates the crystal about the symmetry axis until r' becomes the basal plane instead of c , both these planes being in the orthozone at right angles to the symmetry plane.

Von Fedorow, however, proposes yet another setting, which he finds to agree better with the rule of reticular density. But it is, in the opinion of the author, much to its disadvantage that the reason for it is really based on the peculiar form of the geometrical theory of crystal structure which has been advanced by von Fedorow, and particularly on that part of it which is not so firmly grounded as that which refers only to the derivation of the 230 possible point-systems concerned in crystal structure; this more hypothetical part refers to the nature of what the points represent, and to von Fedorow's idea that all crystals are of either cubic or hexagonal type or of one of those types more or less deformed, which he terms pseudo-cubic

* E. von Fedorow, 'Zeitschr. für Kryst.,' 1909, vol. 46, p. 258.

† 'Journ. Chem. Soc.,' 1893, vol. 63, p. 337; see fig. 1, p. 343, for stereographic projection.

and pseudo-hexagonal or hexagonaloid. Here, like Pope and Barlow in their valency theory, von Fedorow leaves solid incontrovertible ground, which has been fully substantiated quite recently by the interesting experiments of Laue, Friedrich, and Knipping* in obtaining photographic reflections of X-rays from the planes of atoms within the crystal, the planes involved being those containing the points (representing similar and similarly situated atoms) of the underlying space-lattice, as the photographs always show spots arranged with holohedral and never hemihedral symmetry. Von Fedorow retains the same vertical axis as the author in his proposed setting, but rotates the crystal for 180° around it. If, instead of arranging the stereographic projection of a monoclinic crystal as usual in this country, projected on the symmetry plane, we retain the method adopted for the other crystal systems, of making the primitive circle of the projection the prism and primary pinakoid zone, with the poles (100) and ($\bar{1}00$) in front and behind and (010) and (0 $\bar{1}0$) right and left respectively, a method which is often adopted in Germany for monoclinic crystals, we have the projection given in fig. 6. The setting of von Fedorow is represented in fig. 7, which is evidently the same as fig. 6 rotated for 180° in the plane of the paper, that is, about the vertical axis represented in plan by the centre of the projection, which in a rhombic crystal would be the position of the facial pole of the basal plane, $c(001)$, which pole, however, is now displaced forwards in fig. 6 by the angle of monoclinic tilt $16^\circ 50'$,

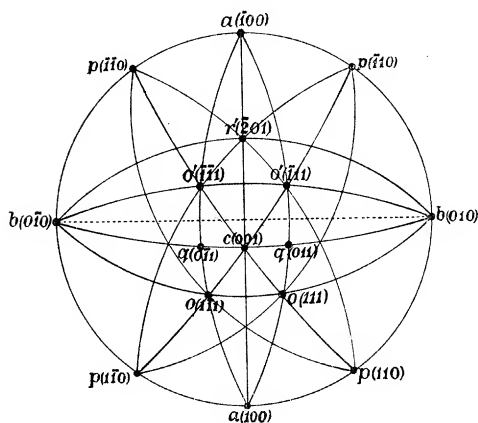


FIG. 6.—Tutton's Setting.

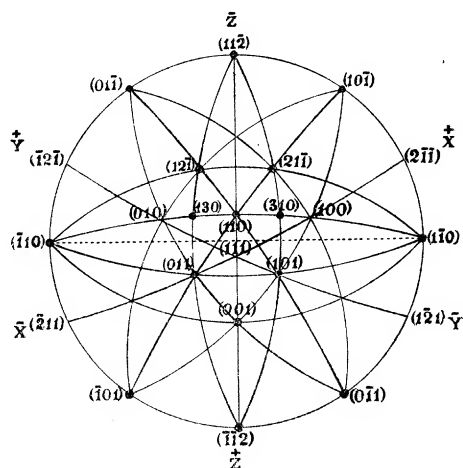


FIG. 7.—Von Fedorow's Setting.

Alternative Settings for Double Sulphates with $6H_2O$.

* 'Sitzungsber. (Math.-Phys. Classe) d. K. B. Akad. d. Wiss. München,' 1912, pp. 303 and 363.

and in fig. 7 to the same extent backwards. In both figures the plane of symmetry is represented by the diameter parallel to the longer edges of the page.

While thus von Fedorow merely alters the author's setting by this rotation for 180° , bringing what was the back of the crystal to the front and *vice versa*, he regards the various poles from an altogether different standpoint. He ignores the monoclinic symmetry, except as being a deformation in one direction, and states that the crystal complex appears to be a hexagonaloid one of cubic type, that is, one of trigonaloid character, which he expresses, in accordance with a method of concise symbols which he employs, thus :—

$$\begin{array}{c} 3o; +13 \\ 47\frac{1}{2} \\ -5\frac{1}{2} \end{array}$$

The letter *o* in the top line indicates the octahedral main structure; the 3 in front of it represents the trigonaloid character, which is similar to the rhombohedral one of calcite, but considerably deformed (in one direction) from the form of the regular rhombohedron; the +13 signifies the number of degrees of monoclinic deformation, on the + side of the trigonal axis *Z*, that is, the angle between the centre of the projection, which in a truly trigonal crystal like calcite is occupied by the pole (111), and the actual position of the pole of the possible face which is analogous to (111) on the deformed crystal. The central number $47\frac{1}{2}$ represents the number of degrees in the principal angle (111):(001), that is, between the basal plane and one of the faces of the primary rhombohedron, on the supposition of trigonaloid character and after imaginary re-deformation of (111) back to true trigonal symmetry, that is, to the centre. The lower number $-5\frac{1}{2}$ represents the angular deviation from 30° of the poles on the primitive circle, that is, of the poles which in trigonal symmetry would correspond to $(\bar{1}01)$ and $(\bar{1}\bar{1}2)$; these are adjacent faces of the two varieties of hexagonal prism in a truly trigonal crystal, and are in the latter 30° apart, but in the neighbourhood of $35\frac{1}{2}^\circ$ (the angle *ap*) in this series of double sulphates ($35^\circ 13'$ in ammonium ferrous sulphate).

Von Fedorow gives the following transformation equations (*loc. cit.*, p. 259) for the conversion of the indices p_1, p_2, p_3 , of any face according to the monoclinic setting of the author, to the corresponding indices q_1, q_2, q_3 , according to von Fedorow's trigonaloid setting:

$$q_1 : q_2 : q_3 = p_1 - p_2 + 2p_3 : p_1 + p_2 + 2p_3 : -2p_1,$$

or the determinants :

$$\begin{vmatrix} 1 & \bar{1} & 2 \\ 1 & 1 & 2 \\ \bar{2} & & \end{vmatrix}$$

The indices of the principal faces according to the two settings are given below, those of the author's setting being in brackets as usual, and those of von Fedorow not, in order to distinguish them :

$$\begin{aligned} c(001) &= 110, \quad r'(201) = 001, \quad a(100) = 11\bar{2}, \quad b(010) = \bar{1}10, \\ q(011) &= 130, \quad o'(\bar{1}11) = 011, \quad p(110) = 01\bar{1}. \end{aligned}$$

It will be clear that the r' -face of the author's setting becomes the rhombohedron face (001) [the $r(001)$ of calcite], and the c -face becomes the face (110) [the $c(110)$ of calcite]. The setting of von Fedorow, thus regarded as a monoclinically deformed rhombohedral one, corresponds to a similarly deformed rhombohedral space-lattice, while the setting of the author corresponds to the second (pinakoidal) monoclinic space-lattice.

The author regards this deformation idea, in cases like this where the difference from 30° is as much as $5\frac{1}{2}^\circ$ and the displacement of (111) from the centre no less than 13° , as an unnecessary complication, and one which is not likely to be followed in actual practice by chemists or crystallographers desirous of making use of the great advantages of crystallo-chemical analysis. Moreover, it will be obvious that if we follow von Fedorow all the way, and accept the assumption of a deformed trigonal symmetry, the following important forms or faces are missing, indicated on fig. 7 by their indices, but without pole-dots: {111} the basal plane; four of the six faces of the hexagonal prism of the first order {2 $\bar{1}\bar{1}$ }, for only two, (11 $\bar{2}$) and ($\bar{1}\bar{1}2$), are generally developed, which are the a -faces (100) and ($\bar{1}00$) of the author's monoclinic setting, the other four faces, (2 $\bar{1}\bar{1}$), (1 $\bar{2}1$), ($\bar{2}11$), and ($\bar{1}2\bar{1}$), having only been seen developed to a measurable extent on one or two crystals of six of the 38 investigated salts of the series as the minute faces p''' (namely, on KCu-, RbCu-, CsCu-, RbCd-, CsCd-, and AmMg-sulphates); and two of the three faces of the primary rhombohedron itself {100}, for only one, (001), is present, while (010) and (100) are generally entirely absent, and have only been seen by the author as minute faces (the m -faces) on three of the 38 salts of the series investigated, namely, KNi-, RbCu-, and CsCd-sulphates. Further, which is even more significant, while it is true that all six faces of the hexagonal prism of the second order {10 $\bar{1}$ } are developed, four of them are the largely and generally predominatingly developed faces of the primary prism $p\{110\}$ of the author's monoclinic setting, while the other two are very small and frequently absent faces of the clinopinakoid $b\{010\}$; that is, two clearly different and very unequally developed forms make up the six faces which von Fedorow proposes to consider as a hexagonaloid prism. Again, the cleavage is only developed parallel to one plane, that of the pair of parallel faces of $r'\{201\}$, that is,

only parallel to one of the three planes of the pseudo-rhombohedron of von Fedorow.

Thus, while it may be true that the faces of the pseudo-rhombohedron possess the maximum reticular density, still there appear to be so many deficiencies as regards development of primary planes, either as faces or cleavage planes, that the author much prefers to accept the simple and obvious monoclinic symmetry of both faces and cleavage as determinative of the setting; and as Wulff's setting is still less to be preferred, both for the reasons given by the author and for the additional ones also advanced by von Fedorow, it is considered preferable to retain the setting which has been adopted throughout all these investigations.

If a clearly hexagonal habit were presented, and all the essential faces well developed, such as in the cases of the simple rhombic sulphates and selenates of the alkalis, where the differences from exactly 30° are only a few minutes, the presence of a pseudo-hexagonal space-lattice could with reason be accepted, and in the descriptions of those salts the author has given the dimensions of the elementary cells of the space-lattice on such an assumption. But in this monoclinic series of double salts such is not the case.

Etch-Figures.—The investigation by Baumhauer* of the etch-figures produced by a small quantity of water on the principal faces afforded results conclusively indicating the presence of holohedral monoclinic symmetry. Besides ammonium ferrous sulphate two other salts of the series were studied, namely, potassium and ammonium nickel sulphates. Two illustrations are reproduced from Baumhauer's memoir, in figs. 8 and 9, but with his lettering of the faces replaced by the letters now assigned to those faces.

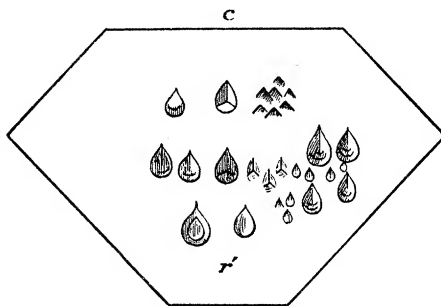


FIG. 8.—Etch-figures on Ammonium Ferrous Sulphate.

Fig. 8 shows the character of the etch-figures on the predominating faces of $r'\{201\}$ in the case of ammonium ferrous sulphate. Fig. 9 reproduces those

* H. Baumhauer, 'Pogg. Ann. d. Phys.,' 1873, vol. 150, p. 619.

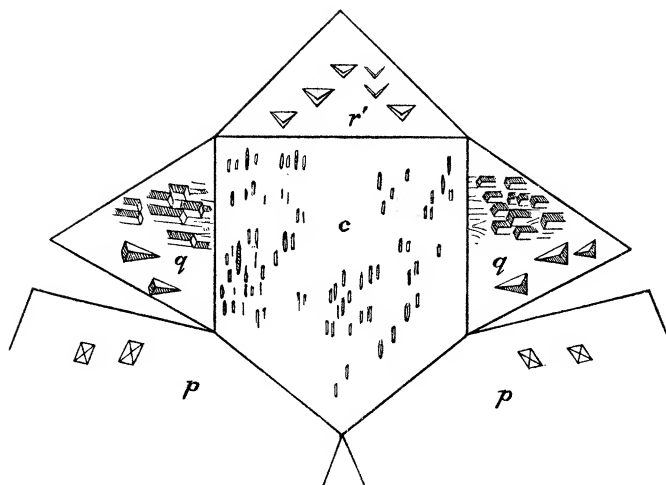


FIG. 9.—Etch-figures on Potassium Nickel Sulphate.

on the four principal forms $c\{001\}$, $p\{110\}$, $q\{011\}$, and $r'\{\bar{2}01\}$ of potassium nickel sulphate. Those on ammonium nickel sulphate were also very similar.

It will be clear that these etch-figures in every case are symmetrical to the single plane of symmetry $b\{010\}$, which is at right angles to the plane of the paper and parallel to the longer sides of the page; they also accord with the presence of a digonal axis of symmetry perpendicular to the plane of symmetry (parallel to the shorter edges of the page). They possess, consequently, both the elements of monoclinic symmetry, and therefore the crystals are holohedral. Moreover, the etch-figures are quite different from such as are usually afforded by a crystal of trigonal symmetry.

Comparison of the Morphological Constants of the Four Salts of the Iron Group.—The crystal-angles, axial angles, and axial ratios of the potassium, rubidium, caesium, and ammonium ferrous sulphates are compared in the next two tables.

As regards the monoclinic axial angle β , its value for the ammonium salt is almost identical with that for the caesium salt. It is noteworthy that a like fact has been observed in all the other groups yet studied, the sulphate and selenate groups containing zinc and magnesium respectively, and the magnesium group of double chromates.

With reference to the axial ratios, it is only possible to infer that the values for the ammonium salt are so similar to those for the analogous alkali-metal salts that true isomorphism undoubtedly exists. It is somewhat singular that the a -values are identical for three of the salts, potassium, rubidium, and ammonium ferrous sulphates.

Comparison of the Interfacial Angles.

Angle.	KFe sulphate.	RbFe sulphate.	CsFe sulphate.	AmFe sulphate.
	° /	° /	° /	° /
$\left\{ \begin{array}{l} ac = (100) : (001) \\ as = (100) : (101) \\ sc = (101) : (001) \\ cr' = (001) : (201) \\ cs' = (001) : (101) \\ s's' = (101) : (201) \\ r'a = (201) : (100) \end{array} \right.$	$\left\{ \begin{array}{l} 75 \ 28 \\ 46 \ 9 \\ 29 \ 19 \\ 63 \ 21 \\ 38 \ 23 \\ 24 \ 58 \\ 41 \ 11 \end{array} \right.$	$\left\{ \begin{array}{l} 74 \ 16 \\ 45 \ 24 \\ 28 \ 52 \\ 64 \ 8 \\ 38 \ 38 \\ 25 \ 30 \\ 41 \ 36 \end{array} \right.$	$\left\{ \begin{array}{l} 73 \ 8 \\ 44 \ 34 \\ 28 \ 34 \\ 65 \ 8 \\ 39 \ 7 \\ 26 \ 1 \\ 41 \ 44 \end{array} \right.$	$\left\{ \begin{array}{l} 73 \ 10 \\ 44 \ 52 \\ 28 \ 18 \\ 64 \ 36 \\ 38 \ 36 \\ 26 \ 0 \\ 42 \ 14 \end{array} \right.$
$\left\{ \begin{array}{l} ap = (100) : (110) \\ pp' = (110) : (120) \\ p'b = (120) : (010) \\ pb = (110) : (010) \end{array} \right.$	$\left\{ \begin{array}{l} 35 \ 36 \\ 19 \ 28 \\ 34 \ 56 \\ 54 \ 24 \end{array} \right.$	$\left\{ \begin{array}{l} 35 \ 23 \\ 19 \ 28 \\ 35 \ 9 \\ 54 \ 37 \end{array} \right.$	$\left\{ \begin{array}{l} 34 \ 49 \\ 19 \ 28 \\ 35 \ 43 \\ 55 \ 11 \end{array} \right.$	$\left\{ \begin{array}{l} 35 \ 13 \\ 19 \ 28 \\ 35 \ 19 \\ 54 \ 47 \end{array} \right.$
$\left\{ \begin{array}{l} eq = (001) : (011) \\ qb = (011) : (010) \end{array} \right.$	$\left\{ \begin{array}{l} 25 \ 56 \\ 64 \ 4 \end{array} \right.$	$\left\{ \begin{array}{l} 25 \ 43 \\ 64 \ 17 \end{array} \right.$	$\left\{ \begin{array}{l} 25 \ 21 \\ 64 \ 39 \end{array} \right.$	$\left\{ \begin{array}{l} 25 \ 24 \\ 64 \ 36 \end{array} \right.$
$\left\{ \begin{array}{l} ao = (100) : (111) \\ oq = (111) : (011) \\ aq = (100) : (011) \\ qo' = (011) : (111) \\ o'a = (111) : (100) \end{array} \right.$	$\left\{ \begin{array}{l} 49 \ 21 \\ 27 \ 37 \\ 76 \ 58 \\ 34 \ 35 \\ 68 \ 27 \end{array} \right.$	$\left\{ \begin{array}{l} 48 \ 35 \\ 27 \ 17 \\ 75 \ 52 \\ 34 \ 51 \\ 69 \ 17 \end{array} \right.$	$\left\{ \begin{array}{l} 47 \ 42 \\ 27 \ 6 \\ 74 \ 48 \\ 35 \ 20 \\ 69 \ 52 \end{array} \right.$	$\left\{ \begin{array}{l} 48 \ 1 \\ 26 \ 49 \\ 74 \ 50 \\ 34 \ 53 \\ 70 \ 17 \end{array} \right.$
$\left\{ \begin{array}{l} co = (001) : (111) \\ op = (111) : (110) \\ ep = (001) : (110) \\ po' = (110) : (111) \\ o'c = (111) : (001) \end{array} \right.$	$\left\{ \begin{array}{l} 34 \ 56 \\ 43 \ 17 \\ 78 \ 13 \\ 57 \ 13 \\ 44 \ 34 \end{array} \right.$	$\left\{ \begin{array}{l} 34 \ 26 \\ 42 \ 48 \\ 77 \ 14 \\ 57 \ 57 \\ 44 \ 49 \end{array} \right.$	$\left\{ \begin{array}{l} 33 \ 57 \\ 42 \ 16 \\ 76 \ 13 \\ 58 \ 38 \\ 45 \ 9 \end{array} \right.$	$\left\{ \begin{array}{l} 33 \ 48 \\ 42 \ 31 \\ 76 \ 19 \\ 58 \ 53 \\ 44 \ 48 \end{array} \right.$
$\left\{ \begin{array}{l} bo = (010) : (111) \\ os = (111) : (101) \end{array} \right.$	$\left\{ \begin{array}{l} 70 \ 6 \\ 19 \ 54 \end{array} \right.$	$\left\{ \begin{array}{l} 70 \ 23 \\ 19 \ 37 \end{array} \right.$	$\left\{ \begin{array}{l} 70 \ 50 \\ 19 \ 10 \end{array} \right.$	$\left\{ \begin{array}{l} 70 \ 43 \\ 19 \ 17 \end{array} \right.$
$\left\{ \begin{array}{l} bo' = (010) : (111) \\ o's' = (111) : (101) \end{array} \right.$	$\left\{ \begin{array}{l} 65 \ 20 \\ 24 \ 40 \end{array} \right.$	$\left\{ \begin{array}{l} 65 \ 15 \\ 24 \ 45 \end{array} \right.$	$\left\{ \begin{array}{l} 65 \ 22 \\ 24 \ 38 \end{array} \right.$	$\left\{ \begin{array}{l} 65 \ 16 \\ 24 \ 44 \end{array} \right.$
$\left\{ \begin{array}{l} sq = (101) : (011) \\ qp = (011) : (110) \\ ps = (110) : (101) \end{array} \right.$	$\left\{ \begin{array}{l} 38 \ 22 \\ 85 \ 55 \\ 55 \ 43 \end{array} \right.$	$\left\{ \begin{array}{l} 37 \ 55 \\ 87 \ 1 \\ 55 \ 4 \end{array} \right.$	$\left\{ \begin{array}{l} 37 \ 28 \\ 88 \ 20 \\ 54 \ 12 \end{array} \right.$	$\left\{ \begin{array}{l} 37 \ 19 \\ 88 \ 4 \\ 54 \ 37 \end{array} \right.$
$\left\{ \begin{array}{l} s'q = (101) : (011) \\ qp = (011) : (110) \\ ps' = (110) : (101) \end{array} \right.$	$\left\{ \begin{array}{l} 45 \ 10 \\ 64 \ 1 \\ 70 \ 49 \end{array} \right.$	$\left\{ \begin{array}{l} 45 \ 16 \\ 63 \ 14 \\ 71 \ 30 \end{array} \right.$	$\left\{ \begin{array}{l} 45 \ 29 \\ 62 \ 38 \\ 71 \ 53 \end{array} \right.$	$\left\{ \begin{array}{l} 45 \ 6 \\ 62 \ 33 \\ 72 \ 21 \end{array} \right.$
$\left\{ \begin{array}{l} r'o' = (201) : (111) \\ o'p = (111) : (110) \\ pr' = (110) : (201) \end{array} \right.$	$\left\{ \begin{array}{l} 34 \ 32 \\ 93 \ 12 \\ 52 \ 16 \end{array} \right.$	$\left\{ \begin{array}{l} 34 \ 57 \\ 92 \ 37 \\ 52 \ 26 \end{array} \right.$	$\left\{ \begin{array}{l} 35 \ 13 \\ 92 \ 34 \\ 52 \ 13 \end{array} \right.$	$\left\{ \begin{array}{l} 35 \ 16 \\ 91 \ 57 \\ 52 \ 47 \end{array} \right.$

From the table of crystal angles and a critical analysis of it are to be derived the following facts: In the cases of 32 of the 36 angles compared the angular change introduced by the replacement of potassium by ammonium occurs in the same direction (increase or decrease of angle) as when rubidium or caesium is the replacing element, and the few exceptions (the angles bo' , $o's'$, $s'q$, and pr') occur in cases where the change is very minute. The effect of the replacement of potassium by ammonium is thus to call forth in general an alteration in the crystal angles of the same sign as when rubidium

or caesium is the replacing base, in which latter cases the changes have been previously shown to follow the order of the atomic weights of the alkali metals.

Comparison of the Axial Angles and Axial Ratios.

	Axial angle.	Axial ratios.
	β .	$a : b : c$
Potassium ferrous sulphate	104° 32'	0·7377 : 1 : 0·5020
Rubidium " "	105 44	0·7377 : 1 : 0·5004
Ammonium " "	106 50	0·7377 : 1 : 0·4960
Cæsium " "	106 52	0·7261 : 1 : 0·4953

In 29 of these 32 cases the amount of the angular change is larger than when rubidium replaces potassium, and in the greater number (24) it is either approximately the same (13 cases) as when caesium is introduced or greater (11 cases) than that amount. The average and maximum changes of angle for the various replacements are set out in the next table:—

Replacement.	Average change.	Maximum change.
K by Rb	32'	72' = 1° 12'
K by Cs	65' = 1° 5'	145' = 2° 25'
K by NH ₄	62' = 1° 2'	148' = 2° 28'

It is thus clear that both the average and the maximum changes of angle which occur when potassium is replaced by ammonium are almost exactly identical with those evoked by the introduction of caesium instead of potassium, and twice as great as when rubidium is the replacing element. Identical conclusions were also drawn from the investigation of the magnesium and zinc groups of double sulphates and selenates. They accord completely with the eutropic character of the relationships between the three alkali-metal salts, and with the merely isomorphous and not eutropic nature of the occurrence of the ammonium salt in the group. As regards the average and maximum changes of crystal angle, the three eutropic salts show direct proportionality to the atomic weights of the three metals.

Volume.

Relative Density.—Seven determinations of specific gravity were made with small perfect crystals selected from five different crops, by the Retgers immersion method, using a mixture of methylene iodide and benzene as the immersion liquid. The following results for the heaviest crystal in each case were obtained:—

I.	Density for	16°·7/4°	.....	1·8618	For 20°/4°	.....	1·8612
II.	„	17°·8/4°	.....	1·8616	„	.....	1·8612
III.	„	17°·6/4°	.....	1·8621	„	.....	1·8616
IV.	„	18°·1/4°	.....	1·8631	„	.....	1·8627
V.	„	15°·8/4°	.....	1·8647	„	.....	1·8639
VI.	„	18°·5/4°	.....	1·8638	„	.....	1·8635
VII.	„	17°·4/4°	.....	1·8649	„	.....	1·8644

The value accepted for 20°/4° is thus **1·864**.

Earlier values (none of them recent) by various workers have varied as much as from 1·81 to 1·89. Considering the excellent unanimity of the above results this wide difference is difficult to understand.

$$\text{Molecular Volume.} \frac{M}{d} = \frac{389\cdot32}{1\cdot864} = 208\cdot86.$$

Molecular Distance Ratios (topic axial ratios).—

$$\chi : \psi : \omega = 6\cdot2094 : 8\cdot4172 : 4\cdot1749.$$

Redeterminations of the Densities of Potassium, Rubidium, and Cæsium Ferrous Sulphates.—In order to render valid all comparisons between the volume constants of these four salts of the ferrous iron group, a series of redeterminations of the specific gravities by the Retgers immersion method have been carried out for the three alkali-metal salts; for the earlier determinations recorded in the author's 1896 memoir* were carried out by the pyknometer method, which is liable to afford lower values for the density, owing to the result being an average one for a large number of crystals in the finely powdered condition, whereas the Retgers method affords the density of the heaviest and therefore most cavity-free crystal.

The results are given below :—

Potassium Ferrous Sulphate, $K_2Fe(SO_4)_2\cdot6H_2O$.

I.	Density for	15°·8/4°	.....	2·1797	For 20°/4°	.....	2·1788
II.	„	15°·8/4°	.....	2·1785	„	.....	2·1776
III.	„	16°·7/4°	.....	2·1748	„	.....	2·1741
IV.	„	16°·8/4°	.....	2·1758	„	.....	2·1751

In determination I the heaviest crystal showed a tendency to rise in the immersion liquid, and in determination III to sink. In determinations II and IV the heaviest crystal remained in the middle of the liquid. The accepted value is therefore **2·177**, for 20°/4°.

Rubidium Ferrous Sulphate, $Rb_2Fe(SO_4)_2\cdot6H_2O$.

I.	Density for	17°·0/4°	.....	2·5184	For 20°/4°	.....	2·5177
II.	„	19°·1/4°	.....	2·5181	„	.....	2·5179

The accepted value is thus **2·518** for 20°/4°.

* 'Journ. Chem. Soc.,' 1896, vol. 69, p. 344.

Cæsium Ferrous Sulphate, $\text{Cs}_2\text{Fe}(\text{SO}_4)_2 \cdot 6\text{H}_2\text{O}$.

I. Density for $18^\circ 5/4^\circ$	2.7964	For $20^\circ/4^\circ$	2.7960
II. ,, $18^\circ 4/4^\circ$	2.7959	,, ...	2.7955

The value accepted for $20^\circ/4^\circ$ is consequently **2.796**.

The values obtained by the pycnometer method in the year 1896 were respectively 2.169, 2.516, and 2.791 for these potassium, rubidium, and cæsium salts containing iron. The new results are thus in all three cases somewhat higher, which was to be expected for the most perfectly cavity-free crystals, perfect little crystals quite free from turbidity having been in all cases used in these new determinations. The highest individual results in 1896 were 2.172, 2.520, and 2.793 for the three respective salts.

Comparison of the Volume Constants of the Iron Group.—The densities and topic axial ratios of the four salts are compared in the next table:—

Volume Constants of the Iron Group.

Salt.	Molecular weight.	Specific gravity.	Molecular volume.	Topic axial ratios.
KFe sulphate	431.16	2.177	198.05	$\chi : \psi : \omega$ 6.0533 : 8.2056 : 4.1192
RbFe ,, ...	523.26	2.518	207.81	6.1692 : 8.3628 : 4.1848
NH_4Fe ,, ...	389.32	1.864	208.86	6.2094 : 8.4172 : 4.1749
CsFe ,, ...	617.26	2.796	220.77	6.2621 : 8.6242 : 4.2716

It will be clear from this table that the molecular volume and topic axial ratios of the ammonium salt are very close to those of the rubidium salt, a result in keeping with the facts derived from the zinc and magnesium sulphate, selenate, and chromate groups previously investigated. As regards the molecular volume, the value for ammonium ferrous sulphate is about one unit higher than that for the rubidium salt, and in the cases of the topic axial ratios the values for χ and ψ are slightly higher and for ω very slightly lower. These small differences between the volume constants of the ammonium and rubidium salts are very much smaller than the differences between the values for the three alkali-metal salts; between the potassium and cæsium salts there is a difference of molecular volume of no less than 22.72 units, and between the potassium and rubidium salts of 9.76 units.

It is thus clear that the replacement of potassium by ammonium is accompanied by practically the same amount of extension of the crystal structure as when rubidium is introduced for potassium, and by a very much smaller change of volume than when cæsium is introduced instead of potassium. Obviously also, there is scarcely any change at all of volume or

alteration of the molecular distances or of the dimensions of the space-lattice unit cell, when rubidium and ammonium are interchanged for one another. This important result is in line with what was discovered by the investigation of the zinc and magnesium sulphate and selenate groups, and of the magnesium chromate group.

Optics.

Orientation of the Optical Indicatrix.—The plane of the optic axes is the symmetry plane $b\{010\}$, as is the case throughout the whole series. The first median line corresponds to the γ refractive index, and the second median line to the α index, the double refraction being of positive sign. The symmetry axis b is the direction corresponding to the β index.

Determinations of extinction in the symmetry plane were carried out with the aid of two excellent section-plates, ground parallel to the symmetry plane with the aid of the cutting and grinding goniometer. The following were the results, which express the position of the second median line behind the normal to $c\{001\}$, for sodium light.

		°	'
Plate I	.....	8	10
„ II	.....	8	6
Mean value	.....	8	8

Hence, the first median line is inclined $8^\circ 8'$ to the inclined axis a , and, as the axial angle $ac = 73^\circ 10'$, the same median line is inclined $8^\circ 42'$ to the normal to $a\{100\}$, and $98^\circ 42'$ to the vertical axis c , forwards, for sodium light. The second median line is $8^\circ 8'$ behind the normal to $c\{001\}$, and lies $8^\circ 42'$ forwards from the vertical axis c . This orientation will be clear from fig. 10. According to Murmann and Rotter the first median line is inclined

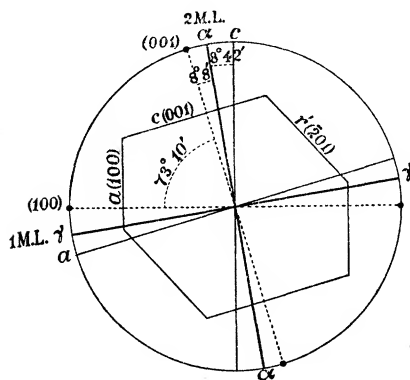


FIG. 10.

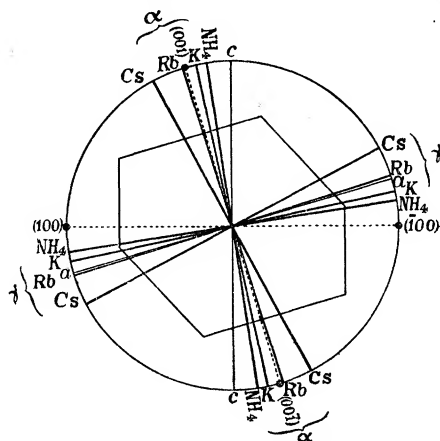


FIG. 11.

Orientation of the Axes of the Optical Ellipsoid.

$99^{\circ} 43'$ to the c -axis, and $7^{\circ} 5'$ to the a -axis. According to Miller the former angle is $99^{\circ} 6'$.

Comparison of the Positions of the Optical Ellipsoids of the Iron Group.—The optical ellipsoid rotates about the symmetry axis b when one alkali base is replaced by another, and the order, in front of the vertical axis, is: Ammonium salt, potassium salt, rubidium salt, caesium salt, as will be clear from fig. 11 and the following table. The latter shows the positions, for the four salts of the group, of that axis of the ellipsoid which is the second median line and corresponds to the refractive index α .

Inclination of the α -Axis of the Indicatrix to the Vertical Axis c , in front,
for Na Light.

	°	'
NH ₄ Fe sulphate	8	42
KFe "	11	57
RbFe "	17	9
CsFe "	28	17

The dispersion of the median lines in the symmetry plane is very small for all four salts, not exceeding 10 minutes between red Li and greenish-blue F light; so that the positions stated above are valid for any wave-length within the limits of experiment. The position of the ellipsoid for the ammonium salt is so that the α -axis lies nearest the vertical axis c of the crystal, $8^{\circ} 42'$ in front of it; while the ellipsoid rotates so that the α -axis moves further and further away from the vertical axis as potassium, rubidium, and caesium successively replace the ammonium, the rotation being a function of the atomic weight of the alkali metals in the cases of these three metallic salts. These rules are exactly similar to those found for the magnesium and zinc groups, both double sulphates and double selenates.

Refractive Indices.—Six excellent 60° -prisms were ground by means of the cutting and grinding goniometer, from perfectly clear and transparent crystals, selected from three different crops. Each prism afforded two indices directly, three of them gave α and β , two yielded α and γ , and the sixth prism furnished β and γ . The results are compiled in the next table.

According to Murmann and Rotter the β -indices for red, yellow, and green light are respectively 1.487, 1.490, and 1.492.

The intermediate index β , corrected to a vacuum (correction +0.0004), is expressed for any wave-length λ by the following general formula:

$$\beta = 1.4784 + \frac{494\ 204}{\lambda^2} - \frac{885\ 610\ 000\ 000}{\lambda^4} + \dots$$

The α -indices are also reproduced by the formula if the constant 1.4784 is reduced by 0.0046, and the γ -indices if it is increased by 0.0074.

Refractive Indices of Ammonium Ferrous Sulphate.

Index.	Nature of light.	Prisms 1, 2, 3.	Prisms 4, 5.	Prism 6.	Mean index.
α . Vibration direction parallel to second median line.	Li.....	1·4836-44	1·4837-9		1·4839
	C	1·4841-7	1·4843-4		1·4844
	Na	1·4866-74	1·4867-8		1·4870
	Tl.....	1·4893-900	1·4893-6		1·4896
	Cd	1·4906-15	1·4909-10		1·4911
	F	1·4922-30	1·4925-6		1·4926
	G	1·4969-74	1·4970-1		1·4971
β . Vibration direction parallel to symmetry axis <i>b</i> .	Li.....	1·4881-9		1·4881	1·4885
	C	1·4886-93		1·4886	1·4890
	Na	1·4910-20		1·4912	1·4915
	Tl.....	1·4940-5		1·4939	1·4942
	Cd	1·4954-62		1·4954	1·4957
	F	1·4969-79		1·4970	1·4972
	G	1·5016-24		1·5020	1·5019
γ . Vibration direction parallel to first median line.	Li.....		1·4954-60	1·4956	1·4957
	C		1·4959-65	1·4961	1·4962
	Na		1·4989-91	1·4987	1·4989
	Tl.....		1·5018-8	1·5016	1·5017
	Cd		1·5032-2	1·5032	1·5032
	F		1·5046-9	1·5046	1·5047
	G		1·5094-4	1·5093	1·5094

Mean of α , β , and γ for Na light = 1·4925.

Change of Refraction by Rise of Temperature.—Determinations of refractive index at 60° C. were carried out with two of the prisms, which furnished α and β , and α and γ , respectively. The results are combined in the following table; the two series of α -values were practically identical, the greatest deviation for any one wave-length being only 0·0002, so that the table is a very trustworthy one.

Refractive Indices of AmFe Sulphate at 60° C.

	α .	β .	γ .
Li	1·4825	1·4865	1·4939
C	1·4830	1·4870	1·4944
Na.....	1·4857	1·4898	1·4971
Tl.....	1·4882	1·4925	1·4998
Cd.....	1·4898	1·4941	1·5014
F	1·4915	1·4958	1·5031

These values are lower than those for the ordinary temperature, the α -values being on the average 0·0013 lower, the β -values 0·0017 smaller, and the γ -values 0·0018 less.

Comparison of the Refractive Indices of the Four Salts of the Iron Group.—The indices of ammonium, potassium, rubidium, and caesium ferrous sulphates are compared in the next table.

From this table it will be apparent that the whole of the refractive indices, and also the mean refractive index, of the ammonium salt are close to the analogous values for the rubidium salt and just slightly higher, but not nearly so high as those of the caesium salt. Thus the indices of the ammonium salt lie between those of the rubidium and caesium salts, and quite near to those of the rubidium salt. In all the other groups investigated, the zinc and magnesium sulphate and selenate groups and the magnesium chromate group, the indices of the ammonium salt also lie between those of the rubidium and caesium salts, sometimes nearer the former and sometimes nearer the latter.

The Double Refraction, as afforded by the difference between the two extreme indices α and γ for sodium light, in the case of the ammonium salt, also lies between the values for the rubidium and caesium salts, but as regards this property nearer to the caesium salt.

Comparison of the Refractive Indices.

Index.	Light.	KFe sulphate.	RbFe sulphate.	NH ₄ Fe sulphate.	CsFe sulphate.
α	{ Li	1·4731	1·4789	1·4839	1·4976
	{ C	1·4735	1·4793	1·4844	1·4980
	{ Na	1·4759	1·4815	1·4870	1·5003
	{ Tl	1·4782	1·4839	1·4896	1·5028
	{ F	1·4811	1·4870	1·4926	1·5061
	{ G	1·4852	1·4916	1·4971	1·5105
β	{ Li	1·4795	1·4847	1·4885	1·5007
	{ C	1·4799	1·4851	1·4890	1·5011
	{ Na	1·4821	1·4874	1·4915	1·5035
	{ Tl	1·4847	1·4898	1·4942	1·5061
	{ F	1·4877	1·4929	1·4972	1·5093
	{ G	1·4920	1·4973	1·5019	1·5137
γ	{ Li	1·4941	1·4949	1·4957	1·5065
	{ C	1·4945	1·4953	1·4962	1·5069
	{ Na	1·4969	1·4977	1·4989	1·5094
	{ Tl	1·4995	1·5003	1·5017	1·5121
	{ F	1·5028	1·5034	1·5047	1·5153
	{ G	1·5071	1·5080	1·5094	1·5198
Mean refractive index $\frac{1}{3}(\alpha + \beta + \gamma)$ for Na light		1·4850	1·4889	1·4925	1·5044
Double refraction, Na _{γ-α}		0·0210	0·0162	0·0119	0·0091

Comparison of the Axial Ratios of the Optical Ellipsoid.—The values of the ratios of the axes of the optical indicatrix and of the optical velocity ellipsoid of ammonium ferrous sulphate have been calculated, and are compared with those for the alkali-metal salts in the following table. The comparison is made both when the β -axis of each salt is taken = 1, and also when the

β -axis of the potassium salt is taken as unity, in order in the latter case to ascertain the effect of replacing one alkali base by another on the dimensions of the two ellipsoids.

Axial Ratios of the Optical Indicatrix.

	$\alpha : \beta : \gamma$	$\alpha : \beta : \gamma$
KFe sulphate.....	0·9958 : 1 : 1·0100	0·9958 : 1 : 1·0100
RbFe „	0·9960 : 1 : 1·0069	0·9996 : 1·0036 : 1·0105
NH ₄ Fe „	0·9970 : 1 : 1·0050	1·0033 : 1·0063 : 1·0113
CsFe „	0·9979 : 1 : 1·0039	1·0123 : 1·0144 : 1·0184

Axial Ratios of the Optical Velocity Ellipsoid.

	$\alpha : \beta : \gamma$	$\alpha : \beta : \gamma$
KFe sulphate.....	1·0042 : 1 : 0·9901	1·0042 : 1 : 0·9901
RbFe „	1·0040 : 1 : 0·9931	1·0004 : 0·9964 : 0·9896
NH ₄ Fe „	1·0030 : 1 : 0·9951	0·9967 : 0·9937 : 0·9888
CsFe „	1·0021 : 1 : 0·9961	0·9879 : 0·9858 : 0·9819

These numbers unite in indicating that the dimensions of the optical ellipsoid, whether it be the indicatrix or the velocity ellipsoid, in the case of the ammonium salt of the iron group lie between those of the rubidium and caesium salts, and when the total change of dimensions is considered, as given by the right-hand set of ratios for each ellipsoid, the values lie much closer to those of the rubidium salt than to those of the caesium salt. It must be remembered, however, that the ellipsoid rotates about the symmetry axis on each replacement, in the order given in the table on p. 378 and illustrated in fig. 11.

Molecular Optical Constants.—These constants have been calculated for the ammonium salt, from the specific gravity and the refractive indices, and the values are compared in the next three tables with the corresponding values for the three alkali-metal salts of the iron group. These latter values have been recalculated, employing the new values for the specific gravities given in this memoir, the results of the redeterminations by the immersion method.

Table of Specific Refraction and Dispersion (Lorenz).

Sulphate.	Specific refraction, $\frac{n^2 - 1}{(n^2 + 2)d} = \pi$.						Specific dispersion. $n_G - n_C$.		
	For ray C(H α).			For ray H γ near G.					
	α .	β .	γ .	α .	β .	γ .	α .	β .	γ .
AmFe ...	0·1536	0·1548	0·1568	0·1570	0·1583	0·1603	0·0034	0·0035	0·0035
KFe	0·1290	0·1305	0·1338	0·1317	0·1333	0·1367	0·0027	0·0028	0·0029
RbFe	0·1127	0·1139	0·1159	0·1151	0·1163	0·1184	0·0024	0·0024	0·0025
CsFe	0·1048	0·1053	0·1064	0·1071	0·1076	0·1087	0·0023	0·0023	0·0023

Table of Molecular Refraction and Dispersion (Lorenz).

Salt.	Molecular refraction, $\frac{n^2-1}{n^2+2} \cdot \frac{M}{d} = m$.						Molecular dispersion. $m_G - m_C$.		
	For ray C(H α).			For ray H γ near G.					
	α .	β .	γ .	α .	β .	γ .	α .	β .	γ .
KFe.....	55·61	56·25	57·71	56·78	57·46	58·95	1·17	1·21	1·24
RbFe	58·96	59·57	60·63	60·24	60·84	61·95	1·28	1·27	1·32
AmFe	59·80	60·28	61·03	61·13	61·63	62·40	1·33	1·35	1·37
CsFe	64·71	65·05	65·69	66·08	66·43	67·09	1·37	1·38	1·40

Molecular Refraction (Gladstone and Dale).

Salt.	$\frac{n-1}{d} M$ for ray C.			Mean molecular refraction for ray C $\frac{1}{3} (\alpha + \beta + \gamma)$.
	α .	β .	γ .	
KFe sulphate.....	93·78	95·05	97·94	95·59
RbFe „	99·60	100·81	102·93	101·11
AmFe „	101·17	102·13	103·64	102·31
CsFe „	109·94	110·62	111·91	110·82

From these tables the following facts are to be derived :—

The specific refraction and dispersion of the ammonium salt are considerably higher than those of the alkali-metal salts of the group, which three latter salts exhibit values progressively diminishing with the atomic weight of the alkali metal.

The molecular dispersion of the ammonium salt lies between the values for the rubidium and caesium salts, and nearer to those of the caesium salt.

The molecular refraction of the ammonium salt, whether calculated by means of the formula of Lorenz or by that of Gladstone and Dale, is very close to, and very slightly higher than, the corresponding (as regards direction in the crystal and the optical ellipsoid) value for the rubidium salt. The mean molecular refraction, in which the influence of direction in the crystal is eliminated, follows precisely the same rule. The rule is, indeed, common to all the double sulphate, selenate and chromate groups of this series yet investigated.

Optic Axial Angle.—Three excellent pairs of section-plates perpendicular to the first and second median lines were obtained by grinding, with the aid of the cutting and grinding goniometer, each pair from crystals belonging

to a separate crop. They all furnished magnificent interference figures when immersed in monobromonaphthalene, with very small inner rings and very sharp hyperbolic brushes, and thus afforded excellent determinations of $2H_a$ with plates 1, 2, and 3, perpendicular to the first median line, and of $2H_o$ with the plates $1a$, $2a$, and $3a$, perpendicular to the second median line. Plates 1 and 2 also gave good interference figures in air, and consequently enabled excellent determinations of $2E$ to be made; but plate 3 was too thick to enable the hyperbolæ to be brought quite up to the double spider lines for measurement of $2E$.

The results are given in the next two tables.

Apparent Optic Axial Angle in Air, $2E$, of AmFe Sulphate.

Light.	Plate 1.	Plate 2.	Mean $2E$.
	° /	° /	° /
Li	132 48	133 27	133 8
C	133 1	133 30	133 16
Na	133 56	134 38	134 17
Tl	135 8	135 15	135 12
Cd	135 25	135 44	135 35
F	135 42	136 11	135 57

Murmann and Rotter obtained $135^\circ 42'$ for the middle part of the spectrum.

Determination of True Optic Axial Angle in Bromonaphthalene.

Light.	No. of plate perp. 1 M.L.	Observed $2H_a$.	No. of plate perp. 2 M.L.	Observed $2H_o$.	Calculated $2V_a$.	Mean $2V_a$.
		° /		° /	° /	° /
Li	{ 1	67 32	$1a$	90 14	76 14	76 16
	{ 2	67 30	$2a$	90 11	76 14	
	{ 3	67 36	$3a$	90 6	76 20	
C	{ 1	67 30	$1a$	90 1	76 18	76 18
	{ 2	67 29	$2a$	90 6	76 15	
	{ 3	67 33	$3a$	90 0	76 21	
Na	{ 1	67 21	$1a$	89 26	76 29	76 25
	{ 2	67 17	$2a$	89 34	76 22	
	{ 3	67 23	$3a$	89 39	76 24	
Tl	{ 1	67 5	$1a$	89 0	76 30	76 28
	{ 2	67 0	$2a$	89 4	76 24	
	{ 3	67 7	$3a$	89 4	76 29	
Cd	{ 1	66 56	$1a$	88 43	76 32	76 30
	{ 2	66 50	$2a$	88 44	76 27	
	{ 3	66 58	$3a$	88 49	76 30	
F	{ 1	66 49	$1a$	88 26	76 35	76 33
	{ 2	66 47	$2a$	88 31	76 31	
	{ 3	66 45	$3a$	88 26	76 32	

Murmann and Rotter give $76^{\circ} 52'$ as the true optic axial angle, and state that $\rho < \nu$, which agrees with the order of the results above given for the various wave-lengths of light. Miller found $2V_a = 75^{\circ} 49'$.

Dispersion of the Median Lines.—Determinations of the true optic axial angle $2V_a$ in toluene, the refractive index of which is almost identical with the mean index of the crystals of ammonium ferrous sulphate, afforded readings which indicated that the first median line is so dispersed in the symmetry plane that it is $9'$ nearer to the axis a for red Li light than it is for greenish blue F light. This result is the mean of two determinations, which yielded the respective values $10'$ and $8'$. The inclined dispersion of the median lines is thus very small.

Effect of Rise of Temperature on the Optic Axial Angle.—Plate 2 was heated in the Fuess heating apparatus provided with the larger axial angle apparatus used in all these measurements, and the apparent optic axial angle in air, $2E$, was found to diminish as the temperature rose. The following values were obtained for 60°C. (corrected with special precaution):—

Optic Axial Angle $2E$ at 60°C.

For C-light	$130^{\circ} 2'$
For Na-light	$130^{\circ} 42'$
For Tl light.....	$131^{\circ} 46'$

The apparent angle $2E$ thus diminishes by about 4° when the temperature is raised 50°C. (from 10° to 60°C.).

Comparison of the Optic Axial Angles of the four Salts of the Iron Group.—This is effected in the next table.

Optic Axial Angles $2V_a$ of the Iron Group.

	KFe sulphate.	RbFe sulphate.	CsFe sulphate.	AmFe sulphate.
	$^{\circ} \quad '$	$^{\circ} \quad '$	$^{\circ} \quad '$	$^{\circ} \quad '$
Li	67 1	73 24	75 2	76 16
C	67 2	73 23	75 0	76 18
Na	67 7	73 21	74 51	76 25
Tl	67 12	73 18	74 42	76 28
F	67 19	73 13	74 31	76 33

The optic axial angle of ammonium ferrous sulphate is thus slightly larger than that of caesium ferrous sulphate, which is the largest of the optic axial angles of the alkali-metal salts. This was also found to be the case in the zinc double sulphate group, while in the corresponding zinc double selenate group the value for the ammonium salt was found to be slightly less than that for the caesium salt. In all three groups the value for the ammonium

salt is thus in the proximity of that for the caesium salt of the same group, sometimes on one side and sometimes on the other. The magnesium double sulphate, selenate, and chromate groups are not comparable, as the phenomenon of crossed axial-plane dispersion enters into those cases, and complicates them.

Summary of Conclusions.

Ammonium ferrous sulphate is a typical member of the monoclinic isomorphous series $R_2M \left\{ \begin{smallmatrix} S \\ SeO_4 \\ Cr \end{smallmatrix} \right\} \cdot 6H_2O$. The clear, transparent, pale bluish-green crystals are distinguished from other members of the series by the exceptionally predominant development of the orthopinakoid of the second order $r'\{\bar{2}01\}$.

The same facts have been found to apply in this double sulphate iron group of salts of the series as were deduced from the previous investigations of the magnesium and zinc double sulphate and selenate groups,* namely, that the ammonium salt of any group is truly a member of the isomorphous series, but not eutropic with the potassium, rubidium, and caesium salts of the group, which three latter salts are strictly eutropic with one another, and follow the rule of progression of the crystal properties with the atomic weight of the alkali metal.

The Crystal Angles.—Small but definitely measurable changes in the magnitude of the crystal angles occur when the potassium in potassium ferrous sulphate is replaced by ammonium, and they are mostly in the same direction as those which accompany the replacement of potassium by either rubidium or caesium. Both the average and the maximum changes of interfacial angles for the ammonium interchange (for potassium) are almost exactly the same as for the replacement of potassium by caesium, and twice as great as when rubidium is introduced instead of potassium (the average and maximum changes of angle being directly proportional to the atomic weights of the alkali metals). Also the monoclinic axial angle β (the axial angle ac , between the vertical and inclined axes) of ammonium ferrous sulphate is almost identical with that of caesium ferrous sulphate.

The Morphological Axial Ratios of the ammonium salt are very similar to those of the analogous potassium, rubidium, and caesium salts, and adequately so to prove true isomorphism in the usually accepted sense, that is, subject to the small variations of crystal angles referred to in the last paragraph.

The Volume Constants.—The molecular volume and topic axial ratios of

* 'Journ. Chem. Soc.,' 1905, vol. 87, p. 1123.

ammonium ferrous sulphate are very close to those of the rubidium salt of the group. *The molecular volume* of the ammonium salt is only one unit different (higher) from that of rubidium ferrous sulphate, whilst a difference of 9.8 units occurs between the volumes of the potassium and rubidium salts, and one of 13 units between those of the rubidium and caesium salts of the group. The topic axial ratios, the expression of the molecular volume in the three dimensions of space, that is, the relative lengths of the edges of the parallelepipedal cell of the space-lattice, for the ammonium salt are very nearly the same as those of the rubidium salt, being as regards χ and ψ slightly higher, and as regards ω very slightly lower.

It is thus clear that the replacement of potassium by ammonium is accompanied by scarcely more volume or dimensional change than when rubidium is introduced instead of potassium. Consequently, the replacement of rubidium by ammonium, two metallic atoms Rb_2 by ten atoms of two ammonium radicles, 2NH_4 , is accompanied by scarcely any appreciable change of volume or of crystal-structure dimensions. This is a weighty conclusion from the point of view of the structure theory. On the other hand, the introduction of caesium or potassium instead of rubidium causes a large volume and dimensional change. These results confirm the conclusions of a similar nature derived from the previous work on the magnesium and zinc groups.

Orientation of the Optical Ellipsoid.—Rotation of the optical ellipsoid about the symmetry axis occurs when one base is replaced by another in this iron group of salts, and the order of the rotation is: Ammonium salt, potassium salt, rubidium salt, and caesium salt. The direction is forwards from the vertical axis, to which one of the axes (α or $\mathfrak{a}$) of the ellipsoid is adjacent (only $8^\circ 42'$ removed) in the case of the ammonium salt.

Refractive Indices.—The whole of the refractive indices for all wavelengths of visible light, and also the mean index, of ammonium ferrous sulphate are near to and slightly higher than those of rubidium ferrous sulphate, and in no case so high as for the caesium salt. Also the *double refraction* for the ammonium salt lies between the values of this constant for the rubidium and caesium salts, but in this case nearer to the value for the caesium salt.

The dimensions of the axes of the optical ellipsoid also lie between those for the rubidium and caesium salts, and much nearer to those of the rubidium salt.

The Molecular Optical Constants.—The specific refraction and dispersion of the ammonium salt are much higher than those of the alkali-metal salts, which three latter salts arrange themselves as regards these constants in the

order of the atomic weights of the metals. The molecular dispersion of the ammonium salt lies between that of the rubidium and caesium salts, and nearer to that of the latter.

The molecular refraction corresponding to each of the three refractive indices, and also the mean molecular refraction, $\frac{1}{3}(\alpha + \beta + \gamma)$, for the ammonium salt is very nearly the same as, and a very slight amount higher than, the corresponding value for the rubidium salt. All these results have been experimentally shown to be independent of the temperature.

Optic Axial Angles.—The optic axial angle of ammonium ferrous sulphate is slightly larger than the largest angle for the metallic salts, that of caesium ferrous sulphate, and the dispersion, both of the optic axes and of the median lines in the symmetry plane, is small between the two extremes of the spectrum, and very similar for all four salts of the group.

Chief Conclusion.—The principal conclusion to be emphasised, as the result of this investigation, and in further confirmation of the deductions from the previous investigations of the zinc and magnesium groups of double sulphates and selenates, and those still more recently* derived from the study of the magnesium group of double chromates, is the following: The ammonium salts are truly isomorphous with the potassium, rubidium, and caesium salts of this large monoclinic series of salts having the general

formula $R_2M \left\{ \begin{matrix} S \\ SeO_4 \\ Cr \end{matrix} \right\} \cdot 6H_2O$, but not eutropic with them, the three latter

salts alone being eutropic (following the law of progression with atomic weight of the alkali metal) amongst themselves; also, it is a singular and very interesting fact that scarcely any change in structural dimensions occurs when ammonium and rubidium are interchanged for each other, that is, when ten atoms ($2NH_4$) replace two atoms (Rb_2), for they do so without appreciably altering the dimensions of the unit cell of the space-lattice.

* 'Mineralogical Magazine,' 1912, vol. 16, p. 169.